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# PATENT SPECIFICATION



Convention Date (United States): July 29, 1922.

221,515

Application Date (in United Kingdom): April 5, 1923. No. 21,069/24.

Complete Accepted: Oct. 6, 1924.

## COMPLETE SPECIFICATION.

### Improvements in Machining the Blades of Hydraulic Turbine Runners.

I, LEWIS FERRY MOODY, Engineer, of 408, W. Chelton Avenue, Germantown, Pennsylvania, United States of America, a citizen of the said United States of America, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

10 This invention relates to an arrangement for machining the blade surfaces of hydraulic turbine runners.

The object of this invention is to provide a hydraulic turbine runner wherein 15 each blade surface is formed as a sector of the same cone and is automatically machined to shape by simple mechanisms such as a lathe or boring mill.

According to the present invention the 20 blades are detachably mounted upon a hub which is adapted to be rotated, as for example by being mounted upon the turn table of a boring mill, in such a manner that the axis of the hub is 25 inclined to the axis of rotation of the table. To this end the runner is rigidly carried by a mandrel on a pedestal which is supported upon the table of the boring mill by means of wedge plates and by 30 properly positioning the runner axis with relation to the table axis and the feeding of a cutting tool along the pitch line of the cone after each cut of the tool, a blade is formed which is a sector 35 of a cone coaxial with the axis of rotation of said table. By inverting the runner upon the mandrel and suitably positioning the axis of the runner with respect to that of the table the rear surfaces of the blades may be similarly 40 machined.

In the accompanying drawings:—

Fig. 1 is a plan view of a runner having blading formed in accordance 45 with this invention and showing means

for setting the runner upon a table of a boring mill or the like for machining the blade surfaces.

Fig. 2 is a vertical sectional view of Fig. 1 taken on a plane containing the 50 runner axis.

Fig. 3 is a vertical elevational view showing the setting up of a blade on the table of a boring mill for machining the 55 blade face.

Fig. 4 is a diagrammatic outline of a blade in circular projection on a meridian plane with the sectional form of the blade shown in section.

Figs. 5 and 6 are blade sections taken 60 respectively on lines 8—8 and 9—9 of Fig. 4.

Fig. 7 is a diagrammatic plan view of the blades of Fig. 1 detached and remounted for simultaneous surfacing by 65 machining.

Fig. 8 is an elevation of the blade assembly shown in Fig. 7.

Fig. 9 is an elevational view of a blade mounted for machining of its concave 70 surface.

Fig. 10 is a diagrammatic plan view of intersecting geometrical figures illustrating a method of determining the 75 runner blade contour.

Figs. 11, 12, and 13 are left side, right side and elevational views respectively of the figures shown in Fig. 10.

Fig. 14 is a diagrammatic development of the intersection of the blade surfaces 80 with the hub cone, and

Fig. 15 is a diagrammatic development of the intersection of the blade edges on the blade cone.

In Figs. 1 and 2 the runner R with 85 four blades 20 has a conical hub 23 with each blade 20 carried on a separate conical section 23<sup>1</sup> of the hub each section being detachably mounted in place on the central hub part or spider 24. 90

[Price 1/-]

The elements of the blades 20 are diagonally directed with respect to the runner axis so as to accommodate the blades to a flow directed diagonally inward and downward as indicated by arrows in Fig. 4. In the formation of this runner the parts are cast to approximate form and the hub section connections finished to an accurate fit so that the sections may be precisely assembled. The blades 20 may have their surfaces finished in usual manner or preferably they may be machined in a lathe, boring mill or other turning machine.

In Figs. 1 to 3 the runner R is shown mounted to have its blade surface 21 machined to accurate conical contour by a simple turning operation. The runner R is rigidly carried by a mandrel 25 of a pedestal 26 supported on wedge blocks 27, the whole being adapted to be mounted on a turn table 28 of a boring mill (Fig. 3) rotating around a vertical axis  $b-b$  so that the axis  $r-r$  of the runner is inclined to the plane of rotation of the table. By suitably angled wedge plates 27 and by properly positioning the runner axis  $r-r$  with relation to the table axis  $b-b$  a blade 20 may be so set that the conical surface 21 desired for it is a sector of a cone coaxial with the axis of rotation  $b-b$  of table 28. By rotation or oscillation of the table 28 and feeding of a cutting tool 29 along the pitch line of the cone the conical surface 21 may be smoothly and accurately machined. With this set up of apparatus only one blade will be surfaced at a time, the blades being brought successively into proper position for machining.

With the conical shaped blading described the form of the blade becomes simple and definite and easy to reproduce with exactness. As shown in Figs. 2 and 3 the meridian sections of the diagonal blades 20 are convex toward the intake instead of curving convexly away from the intake. Such a runner is strong mechanically and being at each point approximately at right angles across diagonal inward flow lines (Fig. 3) is particularly adapted for this type of flow. The smooth machining of the blade surfaces permitted by the simple conical formation gives increased efficiency and higher specific speeds and closer conformity of performance with design. The vane edges can be varied in shape, either being practically straight or formed with a curvature similar to that of the convex elements shown in Figs. 2 and 4, or partaking of the curved outline somewhat as shown by dotted lines in Fig. 1.

The concave or rear surfaces 22 may

also be similarly machined by inverting the runner R on the mandrel 25 and suitably inclining the runner axis  $r-r$  and positioning it with relation to the table axis  $b-b$  so that the table axis coincides with the axis of the cone of which the surface 22 is a sector. This machining of the backs of the blades is in many cases highly desirable and important for the reason that the action of the water is such as to set up a higher pressure on the face of the blade than on the back, this difference of pressure being a source of driving force upon the runner. The back is therefore particularly subject to corrosion due to so-called cavitation, and this tendency is guarded against by providing smooth surfaces.

It may sometimes be advantageous or necessary instead of machining the blades in place on the runner to remove the blade sections from the runner hub and machine them separately, preferably assembling as many of the blades as possible around a central conical axis and in position so that each blade surface is a sector of the cone. All the blades thus assembled may then have their surfaces machined at one operation. For instance, as shown diagrammatically in Figs. 7 and 8, the four runner blade sections of the runner R are shown positioned together around a central vertical axis  $b-b$  with the convex surfaces 21 of blades 20 forming sectors of a cone around this axis. The hub sections 23 will be gripped by special fixtures and supported in the position shown from the boring mill table. Upon rotation of the table the cutting tool will make a cut around each blade in succession and by feeding the cutting tool along the pitch line of the cone all of the blade surfaces 21 will be machined at the same time. In Fig. 9 a blade section is shown in inverted position and with the inner surfaces 22 of the blade 20 forming sectors of an inverted conical surface having its axis at  $b-b$ . With the blades positioned on the mandrel 25 so that their inner surfaces 22 are portions of a conical surface coaxial with the vertical axis  $b-b$  of rotation, the inner surfaces 22 of the blades may be machined as shown at one operation in a manner similar to the machining of the outer surfaces shown diagrammatically in Figs. 7 and 8.

In machining the surface of a blade according to the method of this invention it will often be difficult to machine a portion of the vane near the hub during continuous cutting. This portion of the blade will frequently vary somewhat from the true conical surface in order to provide increased mechanical strength by

increased thickness and fillets where the blade joins the hub. In practice therefore the inner portion of each blade nearest the hub will in general be finished by chipping and hand finishing, the machine finishing being used for the remainder of the blade surface. The surfacing of the innermost portions of the blades is relatively unimportant and it is the outermost portions of the vanes that it is most important to finish accurately by machining, since the relative velocity at these outermost portions with respect to the water is high and accuracy of surface contour is of much greater importance in this part of the blade.

In order to explain the geometrical construction of the conical type of surface and its relation to the conical sections taken in the direction of flow, Figs. 10 to 15 illustrated diagrammatically a method of determination of a blade surface such as 21 of Figs. 1 to 9. Fig. 10 is a plan view looking vertically downward upon a runner placed in its usual position with vertical axis. The runner axis appears as a point at A and the circle M about this point as centre is the outline of the base of a cone representing the runner hub. Since the conical hub 23 of the runner is taken in the direction of flow of water through the runner at the inner end of the blades, the conical hub may be taken to represent any one of such flow sections. Similar sections would be taken across the runner blades at the outer tips and at intermediate points, each flow section thus being in a separate conical surface.

The edges of the blade 20<sup>1</sup> are shown at 41 and 42, each being here taken as a straight line when seen in this projection. These edges will usually have curved contours rather than the straight lines here shown for simplicity of illustration. The blade tip is shown by line 43. The upper surface 21 of the blade lies in a cone, the apex of which is at B and the axis B—K.

For convenience, the cone representing the surface 21<sup>1</sup> of the blade 20<sup>1</sup> has been terminated in a base normal to its axis passing through the point K.

Fig. 11 is a side elevation, looking on the left side of the central view. The cone representing the runner hub 23<sup>1</sup> or conical section is seen with its vertex pointing downward at A and its base at the top of this figure. The cone representing the conical blade surface is seen with its apex at the top of the figure at B and its base in a diagonal plane below.

Fig. 12 is a side elevation looking on the right-hand side of the plan view.

This right-hand side elevation is the direct reverse of Fig. 11. The vane edges which are lines lying in the surface of the cone are indicated by the numbers 41, 42 and 43. The cone representing the runner hub or conical flow section will be referred to as cone A, corresponding to its apex, and the cone representing the blade surface will be referred to as cone B from its apex. In order to show the shape of the flow sections which are obtained when a conical surface is used for the blade in accordance with this invention, it may be supposed that the surface of cone A is unwrapped and developed on a plane surface. The line of intersection of this cone with cone B will appear on this development and will show the shape of the flow section obtained in a blade of this form.

In order to explain the method of designing a runner according to this invention, the geometrical construction for obtaining the intersection of the two cones and for locating this intersection on the flow section or cone A will be briefly explained as follows:—

Referring to Fig. 11 the planes formed by the bases of the two cones A and B are shown extended until they meet in the line shown by the point I. In the plan view, this intersection of the two bases will appear as a horizontal line H shown near the bottom of the sheet. The method of obtaining the intersection of the two cones will be clear if it is illustrated for one point. The first step is to draw an auxiliary construction line A—B connecting the apices of the two cones. A series of planes may now be drawn each containing this line. Every one of such planes will cut from each of the two cones two elements which are also straight lines, and where an element of one cone intersects an element of the other cone will be a point on the intersection of the two cones. It will be sufficient to show this for one such auxiliary plane.

The auxiliary line A—B pierces the bases of the two cones at A<sup>1</sup> and B<sup>1</sup>, respectively, Fig. 10, and therefore an auxiliary plane containing the line A—B will intersect the two bases in lines passing through the points A<sup>1</sup> and B<sup>1</sup>. Two such lines are shown at A<sup>1</sup> L and B<sup>1</sup> L, the lines A<sup>1</sup> L and B<sup>1</sup> L being the traces of the auxiliary plane on the bases of both cones. These traces of course intersect at L in the line I—L which is the intersection of the two bases. Having drawn two such lines as A<sup>1</sup> L and B<sup>1</sup> L, it is now only necessary to find where these lines intersect the peripheries of the bases of the two cones. The base of cone A is bounded by the circle M, which

is intersected by the line  $B^1 L$  at  $N$  and  $P$ . The base of the cone  $B$  is bounded by the ellipse  $Q$ . It is unnecessary to give the construction for drawing this ellipse since it is merely the projection of the corresponding circle in the side elevation. The line  $A^1 J$  intersects the ellipse  $Q$  at  $T$  and  $S$ . Connecting  $P$  and  $N$  with  $A$ , we have two elements of the cone  $A$ ; and connecting  $B$  with  $T$  and  $S$ , we have two elements of the cone  $B$ . All of these elements are in one plane, namely, the auxiliary plane  $B^1 L A^1$ . The corresponding elements will therefore intersect each other. Thus  $A N$  and  $B T$  intersect at  $C$ ; and  $A P$  and  $B S$  intersect at  $D$ . These two points are accordingly points on the intersection of the two cones.

By repeating the above construction, a series of such points is obtained and a curve drawn through them is the line of intersection desired. In order to find the shape of the blade surface in a cross section taken in the direction of flow, the surface of the cone  $A$  is now developed into a plane and the intersection  $x$  of the two cones just found will appear on this development as shown at  $21^1$  in Fig. 14. In this figure is shown the blade  $20^1$  in the intersection. It will be noted that by shifting the position of the blade  $20^1$ , various blade forms can be obtained corresponding to different portions of the intersection  $x$ ; thus the designer is given the opportunity to vary the blade shape through a considerable range by shifting the position of the blade along the curve  $x$  of intersection, and a still wider field of variation can be obtained by using different proportions and positions for cone  $B$ . In Fig. 15 is a development of the blade  $20^1$  outlined on the plane development of the blade cone  $B$ . The line of intersection between the cones is shown at  $X^1$  and the blade edges at 41, 42, 43.

By the use of a simple form of surface, such as the conical surfaces here proposed, a highly desirable simplification and standardization of the forms of runner blades is made possible. For example, if a series of runners are built with helicoidal surfaces, the blade contours can all be of similar form such for example as straight or elliptical edges but of different relative widths; and it then becomes possible to specify the blade form completely by a small number of numerical factors such as the pitch ratio of the helicoid and width or area ratio of the blade surface. The standardization can be carried still further and made to cover the form of blade section and variation of thickness. For example,

if the back of the blade is given the form of a circular arc in cross section, in all runners of a set, the form of blade section is thus standardized. While the invention has been described with particular reference to turbine runners of the diagonal inward flow or axial flow type it is also applicable to runners of the diagonal outward flow type; and the principle of the invention is not confined to the specific examples shown but is intended to cover any modifications within the scope of the appended claims.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. An arrangement for machining the blade surfaces of a hydraulic turbine runner in order that each blade is formed as a sector of the same cone wherein the blades are detachably mounted upon a hub which is adapted to be rotated in such a manner that the axis of the hub is inclined to the axis about which the hub is rotated.

2. An arrangement for machining the blade surfaces of a hydraulic turbine runner according to Claim 1 wherein the blades are detachably mounted upon a conical hub which is rigidly carried by a mandrel on a pedestal supported upon the turn-table of a boring mill by means of wedge plates and the cutting tool is adapted to be fed along the pitch line of the cone after each cut of the tool substantially as described.

3. An arrangement for machining the blade surfaces of a hydraulic turbine runner according to the preceding claims wherein the rear blade surfaces of the runner are machined by inverting the runner upon the mandrel.

4. An arrangement for machining the blade surfaces of a hydraulic turbine runner according to any of the preceding claims wherein the blade surfaces are machined in one operation this being effected by suitably positioning and rotating the blade sections around a central vertical axis substantially as described with reference to Figs. 7 and 8.

5. An arrangement for machining the blade surfaces of a hydraulic turbine runner substantially as described and illustrated with reference to the accompanying drawings.

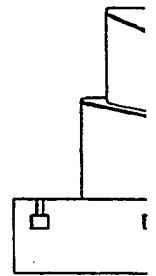
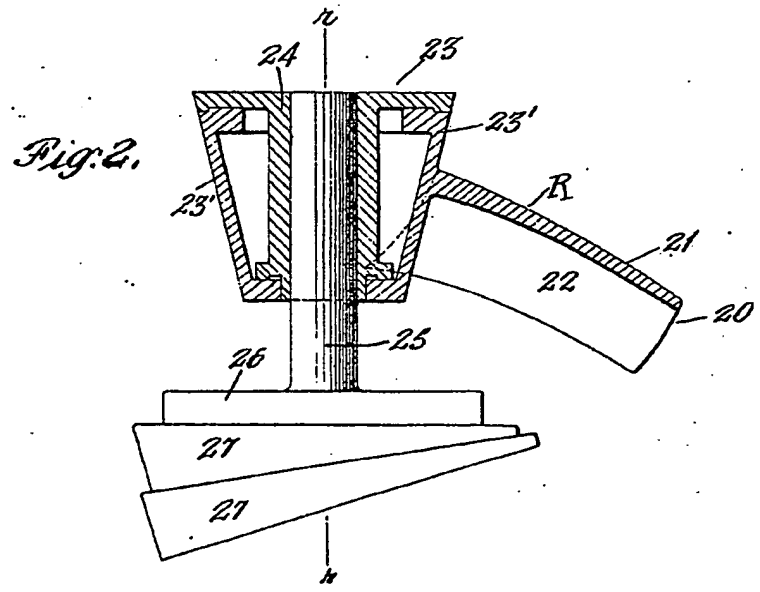
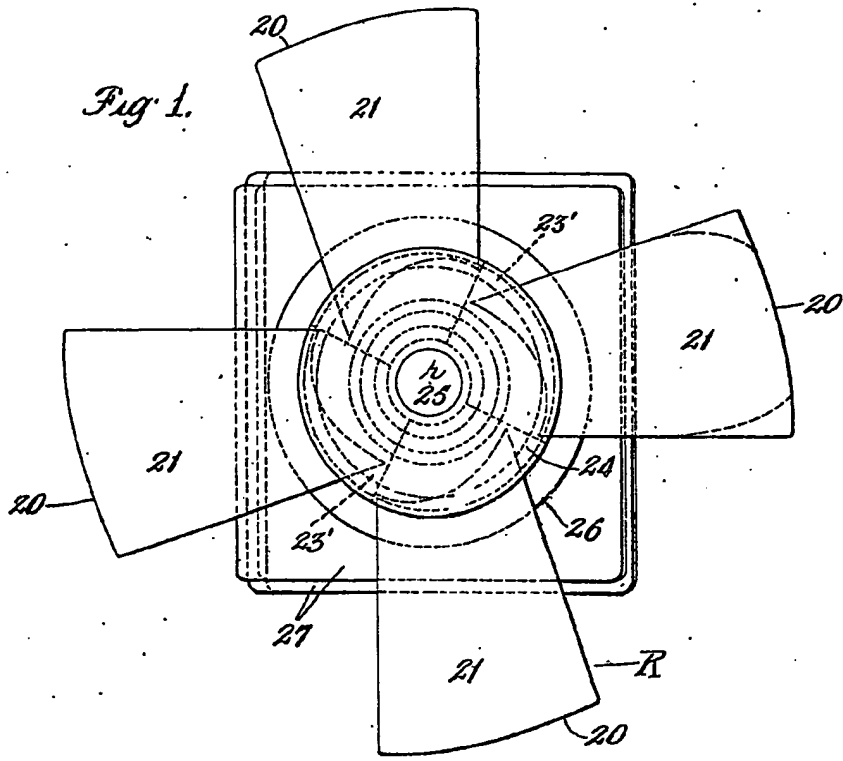
Dated this 5th day of September, 1924.

ABEL & IMRAY,

Agents for the Applicant,

30, Southampton Buildings, London,  
W.C. 2.

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*Fig*

Fig. 3.

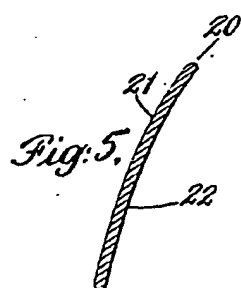
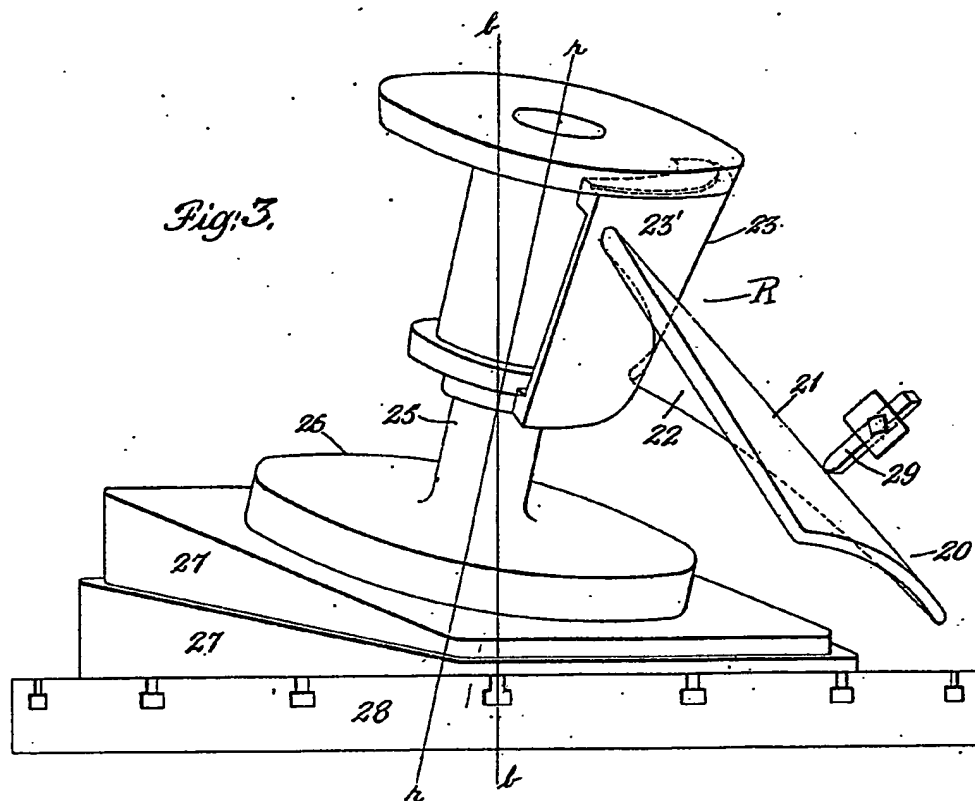


Fig. 5.

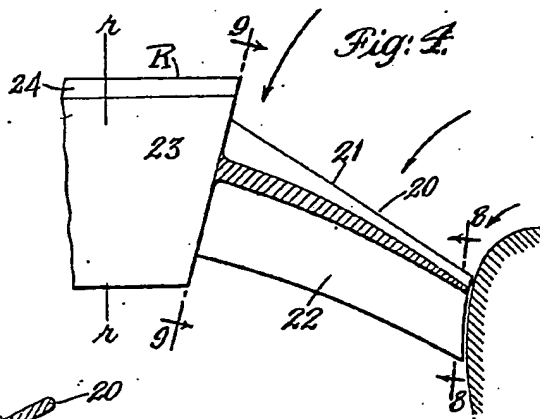


Fig. 4.

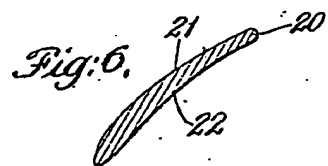


Fig. 6.

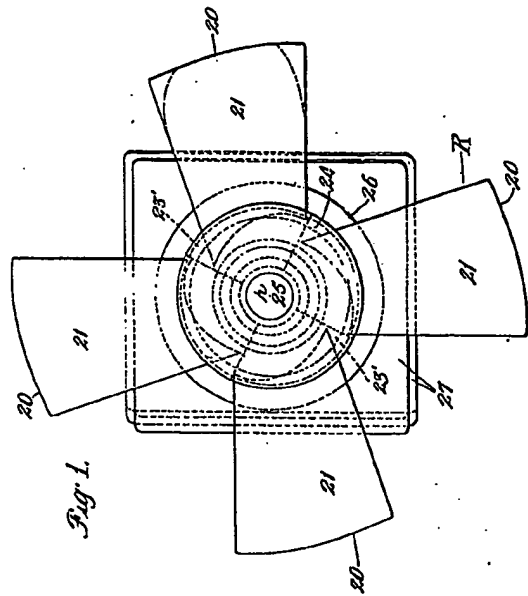


Fig. 1.

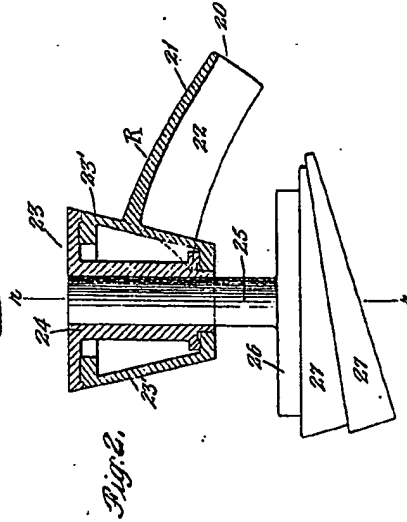


Fig. 2.

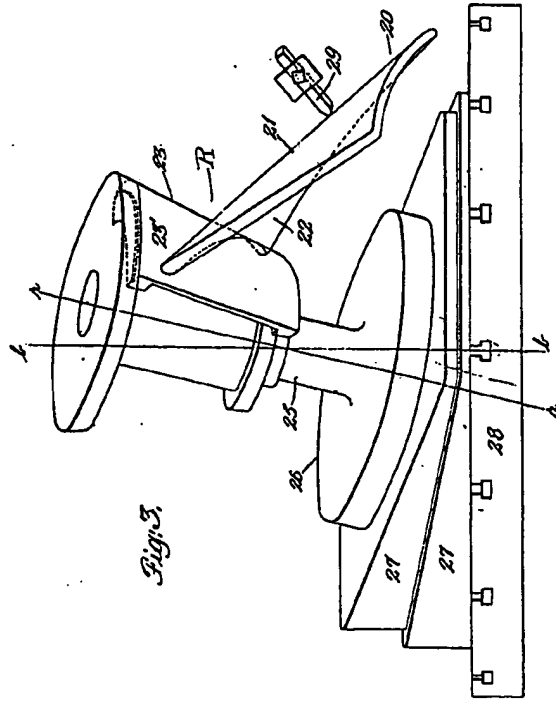


Fig. 3.

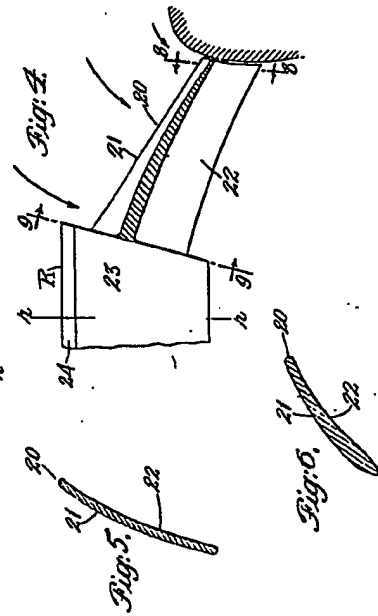


Fig. 4.

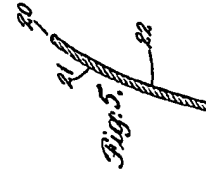


Fig. 5.

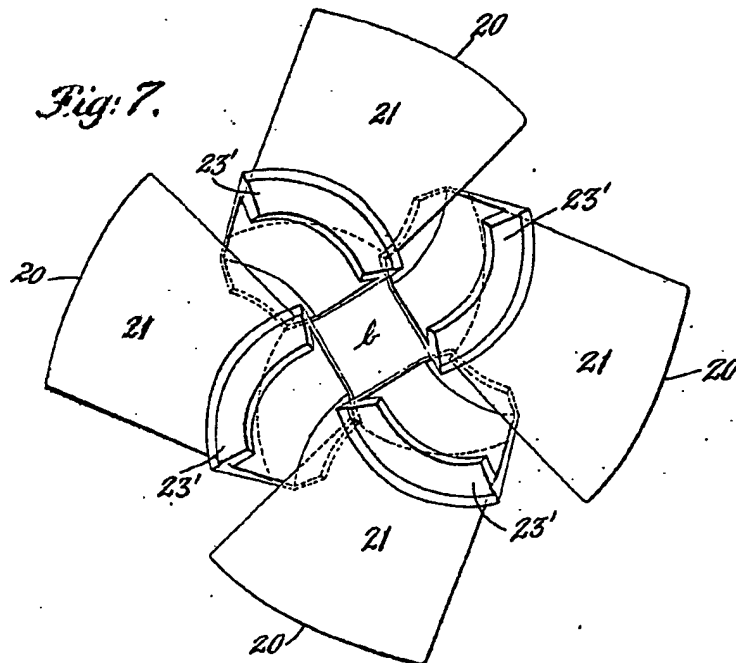


Fig. 6.

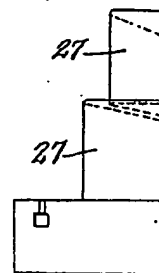
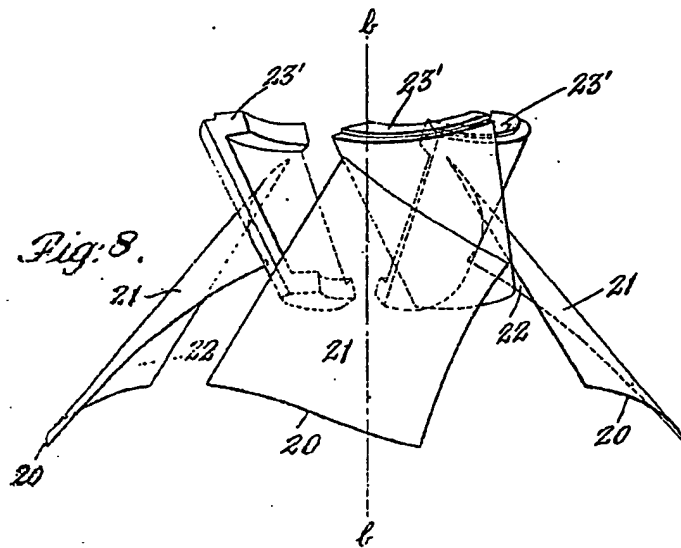
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*Fig. 7.*



*Fig. 8.*



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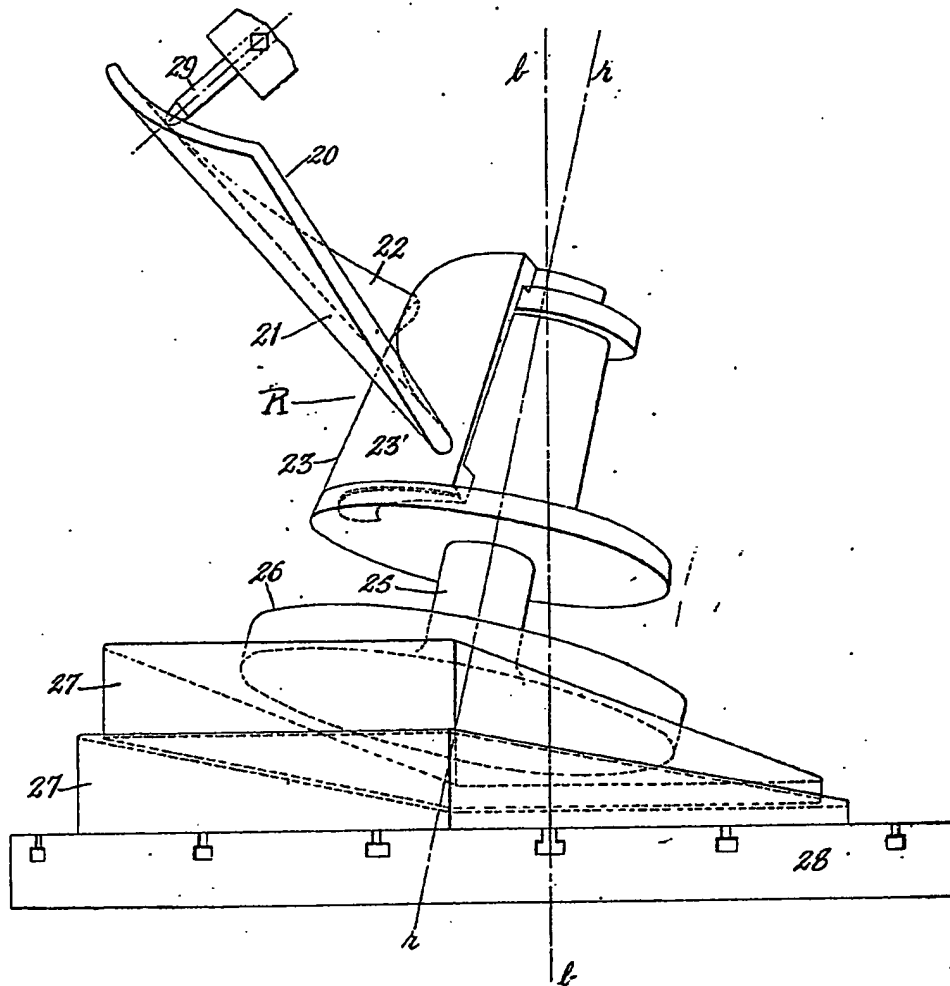


Fig. 9.

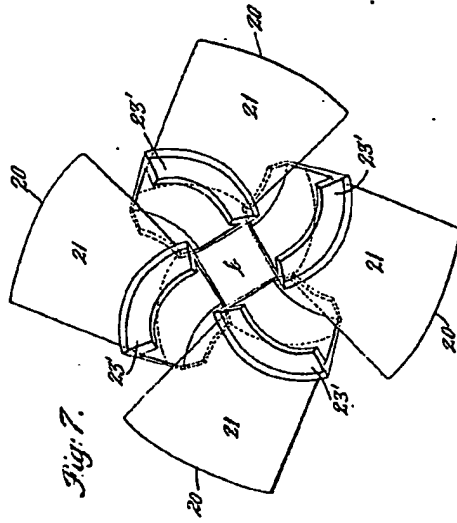


Fig. 7.

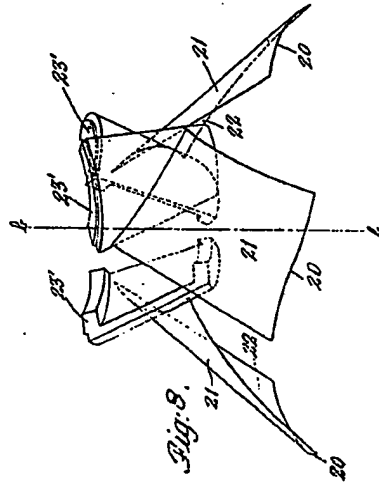


Fig. 8.

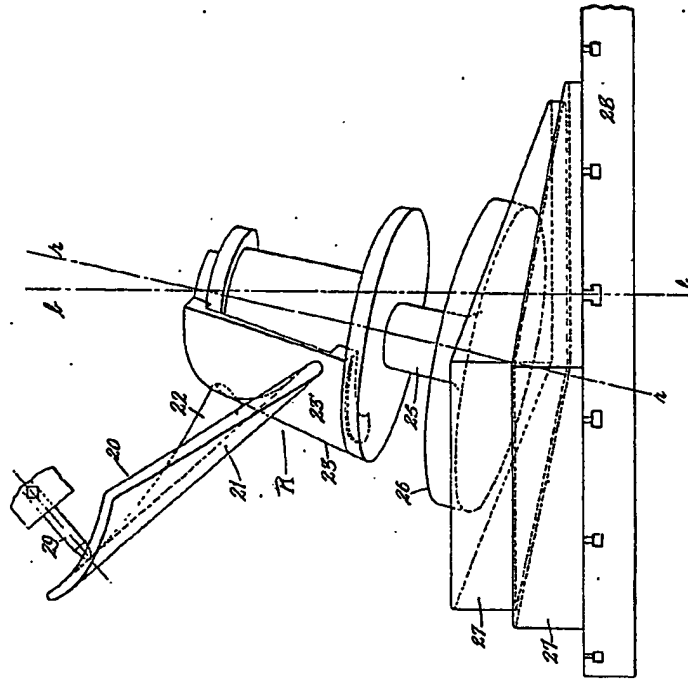
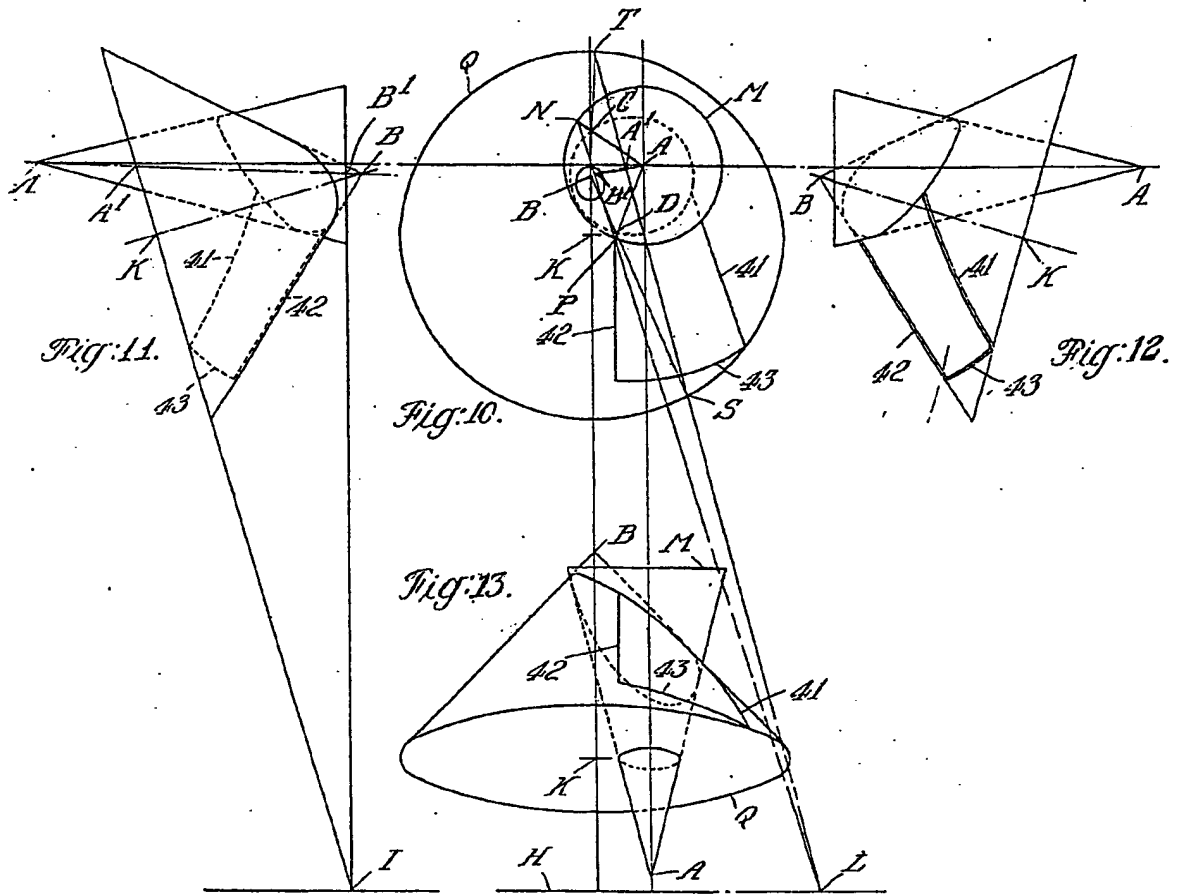


Fig. 9.

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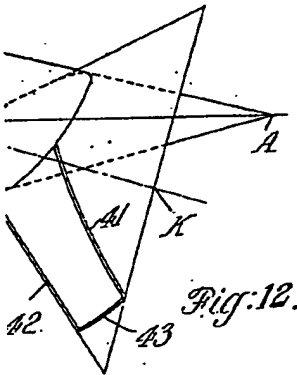


Fig. 14

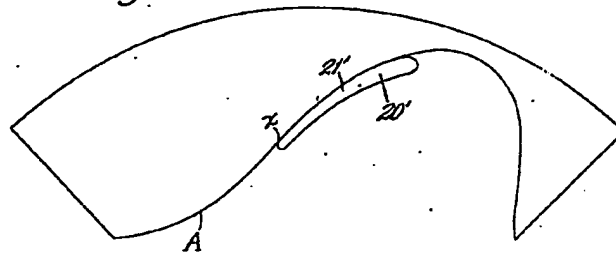
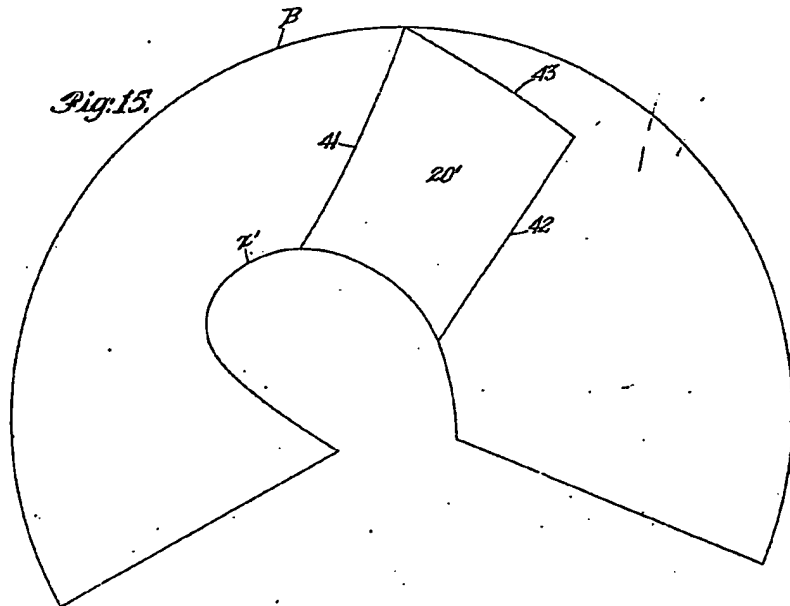


Fig. 15.



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